Hidden Risk is a summary of the major findings of a series of research studies undertaken by the Biodiversity Research Institute in cooperation with The Nature Conservancy.

About Biodiversity Research Institute

Biodiversity Research Institute, headquartered in Gorham, Maine, is a non-profit ecological research group whose mission is to assess emerging threats to wildlife and ecosystems through collaborative research, and to use scientific findings to advance environmental awareness and inform decision makers.

For general information, visit: www.briloon.org
For information about the Center for Mercury Studies, visit: www.briloon.org/bcscenter

About The Nature Conservancy

The mission of The Nature Conservancy is to conserve the lands and waters upon which all life depends. The Conservancy accomplishes its mission through a collaborative approach that links the dedicated efforts of a diverse staff, including over 500 scientists located across the U.S. and in over 30 countries around the world with many partners, including individuals, academic institutions, non-profit organizations, governments, and corporations.

For general information, visit: www.nature.org

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Suggested Citation for This Report


All data collected can be found in:

Mercury is a pollutant that is cause for concern at local, regional, and global scales. While areas of high contamination (known as biological mercury hotspots) may occur near mercury-emitting sources, often they do not. Because mercury released into the atmosphere can circle the world before being deposited, habitats located far from point sources of mercury can still be of major concern to wildlife health. Although great strides have been made to reduce mercury released into the air and water from human activities, this report illustrates that high levels of mercury persist in many wildlife species distributed across many habitat types.

Why Care about Invertivores?

Insect-eating species are integral components of healthy ecosystems, with roles ranging from seed dispersers to insect controllers (see page 5).

The human health effects of mercury contamination are well documented; adverse effects include impacts on cardiovascular health, IQ, workplace productivity, and motor control. Similarly, mercury negatively affects wildlife populations by hindering behavior and reproduction. Past investigations have emphasized adverse impacts to fish-eating wildlife, such as common loons, bald eagles, and river otters. In this report, we synthesize current research and document elevated mercury concentrations in a new group of animals—terrestrial invertivores—that until now has largely been ignored in mercury investigations. We show that mercury concentrations in this animal group are significant enough to cause physiological and reproductive harm, creating a major paradigm shift in ecological research, assessment, monitoring, management, and policy.

Major findings include:

- At-risk habitats and associated indicator species are identified based on the species’ level of conservation concern, relative abundance, and ability to build up mercury in their bodies.
- Current environmental mercury loads have the ability to significantly reduce reproductive success in several songbird species of conservation concern in the northeastern U.S. including the saltmarsh sparrow and rusty blackbird.
- Bats also build up significant body burdens of mercury; individuals from multiple species from all 10 areas sampled exceeded the subclinical threshold for changes to neurochemistry.
- Mercury loading in songbirds is not only restricted during the breeding season; some species, such as the northern waterthrush, build up high levels of mercury during migration and in tropical wintering areas.

What Is an Invertivore?

Often referred to as insect eaters, the songbirds and bats described in this report are more accurately called invertivores because they eat a wide variety of invertibrate species such as spiders, snails, and worms, in addition to insects.

- Standardized monitoring of environmental mercury loads is needed to measure how changes in mercury emissions are related to new U.S. EPA regulations; we suggest that terrestrial invertivores are important indicators for assessing short and long-term changes.

Despite rising global mercury emissions, there are actions that both managers and policy makers can take to limit future ecosystem degradation. Through greater understanding of both the extent of wildlife exposure and harmful impacts to ecosystem health, it is now clear that increased conservation efforts are necessary to reduce this neurotoxin in our environment for the benefit of wildlife and people.

Executive Summary

Mercury: Local, Regional, and Global Concerns

How does Mercury Enter the Environment?

Mercury is a naturally occurring heavy metal found within the Earth’s crust. Used in many industrial processes, mercury is emitted into the atmosphere through a variety of anthropogenic sources. While some source types, such as waste incinerators, have reduced their mercury emissions 95% between 1990 and 2005, utility coal boilers continue to emit more than 50 tons of mercury each year [1]. In December 2011, the U.S. Environmental Protection Agency (EPA) finalized a rule called the Mercury and Air Toxics Standards (MTS) that requires all electric generating plants to upgrade to advanced pollution control equipment by 2016 [2].

Why Are We Still Concerned about Mercury?

Although great strides have already been made in reducing mercury emissions from incinerators, and the MATS rule will likely have the same effect on coal-fired power plants, it is important to continue to monitor the effect of mercury at local, regional, and global scales.

Local Concerns. Researchers have shown that mercury levels in soil are higher in areas close to power plants, with the areas downwind of the power plant usually receiving higher inputs [3]. Combining this influx of mercury into an ecosystem with certain ecological factors, such as precipitation or soil acidification, can lead to a biological mercury hotspot, where we see elevated mercury levels in a relatively distinct geographic area. Areas high contamination is often related to local environmental conditions that have an ability (via a process called methylation) to convert mercury into its most toxic form. For example, wetland habitats are prime areas where this process occurs, and are therefore highlighted in this report.

Regional Concerns. Because the availability of mercury depends on both atmospheric deposition and habitat type, certain regions can be at higher risk to mercury contamination than others. For example, researchers have found high mercury levels across taxa (fish, birds, mammals) in the Great Lakes region [4]. A similar synthesis was completed in the northeastern U.S. and eastern Canada; a third synthesis is currently being planned for the western U.S., Canada, and Mexico (www.wri.org/mercuryconnections).

Global Concerns. When mercury is released into the atmosphere, some settles into the surrounding area but some can move great distances on the prevailing wind patterns before settling back to earth. Because of this, we must look at mercury concerns on a global scale as well, and remember that mercury is truly a pollutant without borders [5].
Impact of Mercury on People

Why Care about the Effect of Mercury on Humans?


The MATS rule will prevent up to:

- 11,000 premature deaths
- 2,800 cases of chronic bronchitis
- 4,500 heart attacks
- 130,000 asthma attacks
- 5,700 hospital and emergency room visits
- 3,200,000 restricted activity days

People are exposed to mercury in all life stages

Adults

High mercury levels in adult males has been tied to increased risk of heart attack [7] and cardiovascular disease [8]

Children

Mercury exposure impacts children throughout life, causing deficits in attention, language, memory [10], and IQ [11]

Pregnant Women

Mercury exposure in utero has been linked to developmental problems related to motor control (such as walking and speech) [9]

Future Work: Brain Science Bridging the Gap between Humans and Birds

In extreme cases, mercury exposure in utero can lead to Minamata Disease, where irreversible brain damage occurs in children born to mothers who consume high amounts of mercury.

Impact of Mercury on Wildlife

Why Care about the Effect of Mercury on Invertivores?

Besides contributing to the beauty of nature, invertivores provide many vital roles within the ecosystem [23]:

Insect Control

Simply put, invertivores eat a lot of insects!

A bluebird family of two parents and five nestlings requires 124g of insects per day. The presence of nesting birds in vineyards reduces the amount of pesticides that are required to maintain healthy crops [24].

A single colony of big brown bats eats nearly 1.3 million pest insects each year. Pest suppression services provided by native bats in U.S. agricultural landscapes is valued at $22.9 billion per year [25].

Seed Dispersal

Almost all the invertivores described in this report supplement their diet with seeds and grains, serving the vital function of dispersing seeds throughout the ecosystem [26].

Impact of Mercury on Invertivores

Impact of Mercury on People

People are exposed to mercury in all life stages

Adults

Majority of dietary intake of methylmercury (MeHg) is due to fish consumption

Children can be exposed to mercury during development

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Elemental mercury released into the ecosystem cannot readily be incorporated into the food web without first being "methylated" or made available to living organisms. The process of methylation occurs with the help of bacteria found primarily in wet areas. This causes large variation in the amount of mercury found in wildlife based on habitat type. For example, atmospheric deposition of mercury can be similar in two adjacent habitats—an upland meadow and a wet bog. If little mercury in the meadow is made available by methylation, then wildlife living in that habitat would be relatively protected from mercury toxicity. The wet habitat of the bog, however, could allow for high rates of methylation, which would be reflected in high mercury levels in the organisms that live there.

**Why Do Habitats Vary in Mercury Levels?**

Wildlife vary in their mercury exposure based primarily on what they eat. Mercury increases as it moves up the food web, a process called biomagnification. Organisms that feed at high trophic levels generally have higher mercury levels than those that feed at lower trophic levels.

**Abiotic (non-living)**

**Atmospheric Deposition**
Mercury released into the air can be incorporated directly into primary producers, such as tree leaves.

**Soil and Leaf Litter**
are the sites of primary mercury methylation by bacteria.

**Biotic (living)**

**Invertebrates** such as pill bugs and millipedes consume leaf litter contaminated with mercury.

**Spiders** eat other spiders and insects, adding 1-2 trophic levels. With each link in a food web, mercury biomagnification increases, meaning that spiders generally have higher mercury content than plant-eating insects [27].

**Wood thrushes**, blackbirds, and sparrows forage on the ground, eating invertebrates from the leaf litter.

**Bats** accumulate mercury from a diverse prey base, including flying insects and spiders.

**Vireos** and warblers forage in tree canopies and consume predatory insects and spiders, making them a top-level predator.

**Interaction of Species and Habitat**

The goal of much mercury research is disentangling the interaction between habitat and species sensitivities. On the following pages, we will illustrate both how individual species vary in mercury based on what they eat, and how specific habitats vary in mercury based on the rate of mercury methylation.
Limitations of Opportunistic Sampling

The data reported here were collected opportunistically over 11 years across 11 states. Most of the bats and birds were sampled as part of larger projects; the different study sites are shown in the sampling locations maps on the adjacent page. We purposefully excluded a vast dataset summarizing wildlife mercury exposure on contaminated sites to focus exclusively on the impact of air pollution. There are many other places, such as U.S. EPA-designated Superfund sites, where mercury levels in wildlife exceed those presented here.

Maximum Blood Levels

The goal of this summary is to answer the question “How bad can mercury contamination get?” Given our opportunistic sampling, we can provide an answer by examining the maximum mercury levels detected in terrestrial invertebrates. We also present more conventional statistics (means and standard deviations—see box at right). For species with large sample sizes, mean mercury values can give insight into overall population mercury loads, but these values can be misleading for species with small sample sizes.

Mercury Effects Levels

In order to calibrate what those blood levels mean in terms of the health of invertebrates, we use data collected in two studies to create effects levels for songbirds and bats. Based on a model of mercury effects on reproductive success in Carolina wrens, we have developed a gradient of effects levels for songbirds (below) [22]. For bats, we do not have data to support a range of effects, instead we must use a preliminary subclinical threshold developed for bats (10 ppm in fur), above which researchers have shown changes to their neurochemistry [30]. Further research is needed to link such subclinical changes with adverse outcomes.

<table>
<thead>
<tr>
<th>Songbird Effects Levels</th>
<th>Risk Level</th>
<th>Reduction in Nest Success</th>
<th>Blood Mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>less than 10%</td>
<td>&lt; 0.7 ppm</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>between 10% and 20%</td>
<td>0.7 - 1.2 ppm</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>between 20% and 30%</td>
<td>1.2 - 1.7 ppm</td>
<td></td>
</tr>
<tr>
<td>Very High</td>
<td>more than 30%</td>
<td>&gt;1.7 ppm</td>
<td></td>
</tr>
</tbody>
</table>

The thermometer graphic is used to illustrate low, moderate, high, or very high risk.

How Do We Assess Mercury Exposure?

How to Interpret Bar Charts

Green bar = Maximum level detected (i.e., this is the highest mercury level that we found)

Error bar = Standard deviation, a measure of variability in the average values (i.e., larger bars mean there are greater differences among individuals)

Black bar = Average mercury level for all sampled individuals

n = sample size (number of individuals sampled)

Maximum Blood Levels

We sampled 1,878 individual songbirds, representing 79 species, between 1999 and 2010. Mercury data by species is presented in order from lowest to highest blood mercury concentrations, regardless of sampling location.

Songbird Effects Levels

We sampled 802 individual bats, representing 13 species, between 2006 and 2008.

Bat Mercury Concentrations

Figure 3: Blood levels of songbird species with blood mercury levels that put them at risk of reduced nesting success. Lines show blood mercury levels associated with 10% (0.7 ppm), 20% (1.2 ppm), and 30% (1.7 ppm) reduced nesting success [22].

Figure 4: Fur levels of bat species sampled in the northeastern United States. Red line shows a preliminary subclinical threshold for mercury exposure in bats (10 ppm in fur), above which researchers have shown changes to their neurochemistry [30].

Bat Sampling Locations

Songbird Sampling Locations

Mercury in Songbirds and Bats of the Northeast
Target Indicators for Mercury in the Northeast

Mercury exposure depends on both species characteristics (such as trophic level) and habitat characteristics (such as wet-dry cycles). To disentangle differences between habitat and species, we chose an indicator songbird species to best represent the mercury risk in each ecosystem type. Because little brown bats are found in many different ecosystems, we chose them as an unrestricted ecosystem indicator. On the following pages, we will describe mercury levels in these species and explain why we see variation among them.

Ecosystems Studied

As expected, birds found in habitats with pronounced wet-dry cycles, such as bogs, beaver ponds, and estuaries, have the highest blood mercury concentrations. Interestingly, we also found elevated blood levels in birds found in upland areas such as deciduous and high elevation forests. In the following pages, we will explain each species’ habitat and food preferences so that you can better understand how they can acquire methylmercury body burdens of concern.

For two species of high conservation concern, the rusty blackbird and the saltmarsh sparrow, we found atmospheric deposition of mercury to reduce nesting success by an average of 10%, which could have implications for already struggling populations.

Figure 5: Blood mercury concentrations of indicator songbirds, representing risk associated with different terrestrial ecosystems.

Figure 6: Geographic area studied. We captured birds and bats across 11 states from Virginia to Maine. Blood mercury concentrations in this report are based on sampling from these 19 study sites. Due to the opportunistic nature of our sampling program, we do not necessarily have complete geographic data for each species, but we are able to discern some trends between different regions.
Forested Rivers and Creeks Indicator

Mercury Risk

Although our findings show that the Louisiana waterthrush is at low risk due to atmospheric deposition of mercury, the negative effect of point-source mercury on aquatic ecosystems is well documented and mercury has been shown to persist in rivers more than 80 miles from its original source [31]. Both habitat and dietary habits compound to create a higher risk of mercury exposure along heavily contaminated rivers. For species like this warbler, which face population declines due to habitat loss, mercury contamination poses an added ecological burden.

Habitat

When breeding in the eastern United States and southern Canada, the Louisiana waterthrush requires fast-flowing streams or small rivers that wind through closed-canopy, hilly, deciduous forest. This bird nests on the ground along the riverbanks—in small hollows, under fallen logs, or in the exposed roots of upturned trees. Its habitat requirements are similar in its wintering grounds in the West Indies, Central America, and northern South America. In areas of the Northeast with pronounced spring runoff, these types of streams have extreme wet-dry cycles, leading to increased mercury methylation.

Feeding

Foraging at the edge of flowing water, this warbler eats many aquatic invertebrates, along with higher trophic-level organisms such as spiders, amphibians, and small fish.

The Louisiana waterthrush is not a thrush at all; it belongs in the warbler family. However, unlike other warblers, this species prefers to spend its time near swift moving forested streams and small rivers. Its song, a mix of high-pitched ringing sounds and metallic chirps, is loud enough to be heard above the rushing water of its favored habitat.

A distinguishing characteristic of the Louisiana waterthrush is its tail bob; it constantly wags its tail as it forages along the ground (genus and species names both mean “tail-wagger”). Some suggest that this tail-wagging may help to camouflage the bird against the moving waters.

Other Birds of Conservation Concern in this habitat: prothonotary warbler, yellow-throated warbler, and hooded warbler.

Recommendations

Protecting forests and waterways on both breeding and wintering grounds are important conservation actions for this species. Research should focus on habitat use and ecology in the tropical regions to which this bird migrates. Also, more information is needed on migration routes and stopover habitats.

Figure 7: Geographic differences in mercury exposure in Louisiana waterthrushes. While sample sizes are low for this species, our data suggest biological mercury hotspots in southern New York and southwest Virginia.
The wood thrush, a bird of the deep forest, sings a haunting and complex array of songs that have been described as flute-like, ethereal, hollow, sometimes exhibiting an electrical quality. A complicated syrinx (song box) allows this thrush to sing two notes at once, creating the effect of a harmony with itself; the males take full advantage of this talent when courting.

In the mid-19th century, Henry David Thoreau, one of the earliest and most profound environmental writers, declared the abundant wood thrush an indicator of the health of a forest; sightings of the wood thrush have become increasingly rare over the last four decades.

Other Birds of Conservation Concern in this habitat: cerulean warbler, worm-eating warbler, Kentucky warbler, and Swainson’s warbler.

Habitat
This thrush spends its breeding season in a wide variety of deciduous and mixed forests throughout the eastern half of the United States—from the Gulf States to southern Canada and from the eastern edge of the Great Plains to the Atlantic Coast. It prefers thickly forested areas with a dense understory, moist soil, and abundant leaf litter (also prime sites of mercury methylation). In early fall, the wood thrush migrates to the broad-leaved forests of Central America. They often return to the same breeding and wintering grounds each year.

Feeding
The wood thrush feeds mostly on invertebrates at ground level, foraging in leaf litter, and on fruits from shrubs (especially important during migration).

Mercury Risk
Since the wood thrush feeds primarily on the forest floor by moving leaf litter to locate prey, the pathway of methylmercury through its prey is likely connected with the organic soil and the leaf litter. High mercury levels in soil relate with high mercury levels in the wood thrush; in these same areas, soil calcium levels were low, most likely due to acid rain. For a breeding bird feeding in this habitat, this is a worrisome combination. Wood thrush populations are declining significantly across their range; and in New York and neighboring states that decline is linked to the loss of calcium, a vital nutrient for reproduction [32].

Upland Forests Indicator

Mercury Risk
Potential Moderate Hg Risk

Current and Future Risks
Causes for the recent wood thrush decline may include forest destruction and fragmentation, as well as acid rain. The combination of high mercury levels in areas with acid rain may combine to create a “1-2 punch” that is more damaging to the population than either effect in isolation. However, more research is needed to better understand this complex interaction.

Recommendations
Protecting large tracts of forests in breeding areas, as well as maintaining habitat that these birds need for migration are critical for the survival of this species.

Wintering grounds in Central America must also be protected to ensure the long-term success of wood thrush populations. Further work in understanding the ecology of this species on its wintering grounds will provide valuable clues to understanding population declines.

Figure 8: Geographic differences in mercury exposure in wood thrushes. Wood thrushes in Virginia and southern New York show elevated mercury levels compared to the other sampling areas.
Based on habitat and diet alone, we would expect Bicknell’s thrush to be relatively removed from mercury exposure. This is not the case because high elevation mountain areas are prone to increased precipitation, and therefore, increased pollution from cloud water [33]. These conditions are ripe for the production of methylmercury. High elevation species such as the Bicknell’s thrush have proportionally higher mercury levels than associated low-elevation mountainside neighbors, such as other thrushes.

Habitat
This species is extremely restricted in its habitat and range. It breeds in dense areas of stunted balsam fir and spruce found at high elevations from the northern Gulf of St. Lawrence and easternmost Nova Scotia, to the White Mountains of New Hampshire, the Green Mountains of Vermont, and the Catskill Mountains of New York State. Its wintering grounds are also restricted; this species migrates to one of only four islands in the Greater Antilles, in the Caribbean Sea.

Feeding
These birds feed primarily on insects, especially beetles and ants; they will eat wild fruit during migration. During the breeding season, they feed on or close to the ground, but will also forage for food in the branches of trees, sometimes fly-catching from their perches.

Mercury Risk
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Figure 9: Geographic differences in mercury exposure in Bicknell’s thrushes. Due to their particular habitat requirements, Bicknell’s thrush are not found in all the geographic region studied, but those captured in western Maine show higher mercury levels than other areas.

Recommendations
Efforts are needed to continue to protect or manage known and potential breeding habitat; land management agencies can partner with timber companies to develop and implement best management practices to maintain a target amount of Bicknell’s thrush habitat in working forests. It is equally important to protect, manage, and restore known and potential winter habitat. Working with and developing strong collaborative efforts with Caribbean partners is critical to the protection of habitat on the wintering grounds. It is also important to identify migratory stopover sites, routes, and patterns.

In 1904, John Burroughs, literary naturalist in the tradition of Thoreau, described the song of the Bicknell’s thrush as a “musical whisper of great sweetness and power.” However, the plaintive call of this mid-sized thrush is rarely heard by those other than the most intrepid bird enthusiasts and ornithologists. Reclusive and elusive, this bird is one of the rarest songbirds in North America.
Habitat

The vast boreal region of Canada and Alaska along with the Acadian forest of eastern Canada and New England represent the core breeding habitat of the rusty blackbird. They select forested wetlands, muskeg swamps, and beaver bogs for breeding, laying speckled blue and brown eggs in nests constructed in the stunted spruce or fir trees typical of these habitats. In early autumn the blackbird migrates to the southern U.S. for the winter, feeding on invertebrates and grains in both wet bottomlands and dryer uplands, such as pecan plantations.

Feeding

The rusty blackbird feeds preferentially on aquatic insect larvae and large adult flying insects, taking advantage of spring emergence events while breeding. In winter they become opportunistic as insects become scarcer, feeding on grains and tree masts.

Mercury Risk

Rusty blackbirds are exposed to levels of mercury that may negatively affect them while breeding in New England and Maritimes Canada; concentrations of mercury for individuals breeding in the Northeast are more than four times that of those breeding in Alaska, with an average concentration of about 0.9 ppm. The high mercury exposure is due to a diet based on aquatic macroinvertebrates and spiders, allowing for multiple intermediate trophic levels and a high bioconcentration of aquatic mercury. Additionally, the acidic water typical of their breeding habitat promotes a high bioavailability of mercury for uptake [34].

Potential Very High Hg Risk

Rusty Blackbird (Euphagus carolinus)

Named for its rust brown winter plumage, the rusty blackbird is occasionally mistaken for its near relative, the common grackle. Although rusty blackbirds were once abundant enough to “blacken the fields and cloud the air” during migration, today migrating and wintering flocks rarely exceed a few dozen due to an unexplained yet dramatic population crash.

Unlike many other North American blackbirds, rusty blackbirds will form monogamous pairs while breeding that will often persist the following breeding season. They can be aggressive while breeding, attacking larger species, such as jays, that could prey on their young. When food is scarce during harsh winters, these blackbirds have been known to attack and eat other songbirds.

Other Birds of Conservation Concern in this habitat: olive-sided flycatcher, bay-breasted warbler, and Canada warbler.
Saltmarsh Sparrow (Ammodramus caudacutus)

Habitat
Salt marshes are found along the intertidal shores of estuaries and sounds where salinity ranges from freshwater (further inland) to ocean levels (coastal). These coastal marshes, subject to the ebb and flow of the tides, often experience rapid changes in salinity and temperature, to which the birds must adapt. The saltmarsh sparrow migrates only at night to their wintering estuaries in the southeastern United States.

Feeding
Saltmarsh sparrows feed mostly on insects, spiders, amphipods, and small snails, supplementing this diet with seeds and wild rice. When foraging, they run in short spurts, walk, or slowly hop.

Mercury Risk
Saltmarsh sparrows showed elevated blood mercury concentrations across much of their breeding range, most likely due to both dietary and habitat preferences that put them at high risk to mercury exposure [35]. Findings of elevated blood mercury concentrations at several sites suggest that mercury accumulations may be high enough in the blood of saltmarsh sparrows to cause regular nest failure at a rate that may put local populations at risk. Mercury, as a neurotoxin, is especially a problem for these estuary dwellers, as it may affect the sparrow’s ability to time its nesting patterns with the tides.

In her Hymn to Aphrodite, the ancient Greek poet Sappho describes “wing-whirring sparrows” pulling the goddess’s chariot across the sky. Throughout history, these common birds—the sparrow family is the largest bird family in the world—have found their way into classic literature from the Gospels, to Shakespeare’s plays, to Stephen King’s thrillers.

The saltmarsh sparrow, now genetically distinguished from the Nelson’s sparrow, spends its entire life cycle in the transitional areas between land and sea. During the breeding season, the non-territorial males have earned a reputation for promiscuity; they often breed more than once during a season. These birds synchronize nesting with the tides, fledging their young in only eight days.

Other Birds of Conservation Concern in this habitat: Nelson’s sparrow, seaside sparrow, clapper rail, and willet.

The saltmarsh sparrow is an excellent indicator species for contaminants in estuaries: they are endemic to the region; spend their entire life cycle in saltmarsh habitats; and tend to eat high in the food chain. Limiting mercury exposure is critical. Salt marsh managers must identify and reduce sources of mercury by implementing Best Management Practices (BMP) for storm water management where it affects the saltmarsh, use vegetative buffers, remove sources of mercury such as landfills, and support regulations to reduce the amount of mercury entering the water system.

Because these birds are especially vulnerable to rising sea levels as a result of climate change, it is important that land use planners and decision-makers extend coastal protection further inland.
A billion per year in the U.S. [25]. Voracious eaters is valued at $22.9 in insects in one night. The service can consume up to its body weight 1,200 mosquitoes in an hour; this bat be about three inches long and weighs the little brown bat, which grows to large as 300,000 individuals. In North America. Now, however, because of a fungus causing white-nose syndrome, little brown bat populations have declined dramatically and are now being considered for federal listing. Not a bat species, including the Indiana bat (Myotis sodalis), are already on the federal endangered species list and a petition has been filed to list little brown bats. Beyond the urgent need to understand and mitigate the effects of WNS, bats should be protected through management of forests and cave exploration, as well as by limiting pesticide use. Debunking myths through education will help raise public awareness as to the value of bats.

Recommendations

Northeastern bats are in danger due to multiple threats, including WNS, habitat loss, pesticide use, mercury pollution, and wind-power development. The U.S. Fish and Wildlife Service is coordinating a national management plan to address WNS, but more research is needed to better understand other threats that bats face.

Bats are long-lived and have the potential to accumulate high concentrations of mercury over time. High mercury levels may lead to a myriad of problems such as compromised immune systems, which would make it harder to fight infections like white-nose syndrome. The interaction of bats and windfarms is an additional concern as bats approaching the blades of wind turbines may suffer from pulmonary death (i.e., the bursting of capillaries). The ability of bats with elevated mercury body burdens to avoid wind turbines requires further investigation.

Habitat

The little brown bat is found in a wide range of forested areas throughout North America, from southern Alaska eastward through the southern half of Canada to Newfoundland, south through most of the continental United States, and in higher elevation forested regions of Mexico. They roost in tree cavities and caves, as well as in barns and attics.

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Figure 12: Bat sampling locations occur across a variety of habitats within the Northeast, making bats valuable candidates for monitoring programs. Map landcover types based on the National Land Cover dataset [36].

Figure 13: Mean bat fur mercury concentrations for little brown bats in different geographic regions in the Northeast. All regions sampled have individuals with fur concentrations that exceed the 10 ppm preliminary subclinical threshold (red line). At concentrations above 10 ppm, researchers have shown changes to little brown bat neurochemistry [30].
Primary Indicator: saltmarsh sparrow
Secondary Indicators: Nelson’s sparrow, seaside sparrow, clapper rail, willet

Primary Indicator: rusty blackbird
Secondary Indicator: olive-sided flycatcher, bay-breasted warbler, Canada warbler, Virginia rail, spotted sandpiper

Primary Indicator: little brown bat and our songbird indicator species
Secondary Indicator: all North American bat and songbird species, particularly those associated with wetland habitats

Large fluctuations in water levels within reservoirs can intensify the amount of mercury methylation in an ecosystem [41, 42]. The repeated wetting and drying of water body edges allows the bacteria that methylate mercury to thrive and increase the amount of biologically available mercury. The most reasonable way to control this methylation is to maintain more constant water levels in these reservoirs, particularly in late summer and early fall.

Because of its prevalence in various industrial processes and wastewater treatment plants, mercury has historically been released in varying quantities into many different water bodies throughout the United States. Estuaries are often the final destination for this source of mercury, and the high degree of methylation in coastal wetlands allows for much of it to become available to wildlife [35]. Although many of these point sources have known inputs, there are many that are unknown and unexplored. In some cases, the solution can be as easy as discovering and cleaning up the legacy dump site. Without intensive biomonitoring in our nation’s estuaries, we will not be able to determine where these “hotspots” of high mercury levels in wildlife occur.

Mercury emissions must be controlled at the source, and the U.S. EPA has recently finalized its Mercury and Air Toxics Standards (MATS) rule to regulate mercury emissions from power plants in the United States [2]. Implementation of this rule is necessary for protection of ecosystem health, including areas particularly sensitive and/or close to sources that are likely biological mercury hotspots [41].

Primary Indicator: little brown bat and our songbird indicator species
Secondary Indicator: all North American bat and songbird species, particularly those associated with wetland habitats

Management Recommendations

High Elevation Forests

Reduce acid deposition

Birds and other wildlife living in forests are often limited by the amount of calcium available for uptake. Acid deposition created from the burning of fossil fuels can intensify the leaching of calcium from the soil [32]. In areas that are also subject to a high amount of mercury deposition, this can become a dangerous combination of threats. Besides the need for control of mercury emissions, forests can be managed for reducing soil acidification that will alleviate the effect of multiple environmental stressors.

Primary Indicator: Bicknell’s thrush
Secondary Indicators: blackpoll warbler, yellow-bellied flycatcher

Upland Forests

Improve fire management

Forest fires have the ability to mobilize mercury sequestered in the soils and vegetation of forests [37, 38]. This mercury is then free to enter the atmosphere or be remobilized into nearby habitats and then ingested by organisms. Fire is often necessary for the overall health of forests, but allowing for more frequent, less severe forest fires will reduce the risk of large scale mobilization of mercury into the ecosystem.

Primary Indicator: wood thrush
Secondary Indicators: cerulean warbler, worm-eating warbler, Kentucky warbler, Swainson’s warbler, Acadian flycatcher

Forested Rivers and Creeks

Restrict logging near water bodies

Logging near forested rivers and creeks not only enhances erosion, it also remobilizes mercury previously sequestered in the soils [39, 40]. By restricting logging near water bodies, direct movement of mercury into the watershed can be minimized. The contamination of streams and rivers in one place may have significant ramifications more than 80 miles downstream [31].

Primary Indicator: Louisiana waterthrush
Secondary Indicators: prothonotary warbler, yellow-throated warbler, hooded warbler, northern waterthrush, Canada warbler

Artificial Reservoirs

Control reservoir water level fluctuations

Large fluctuations in water levels within reservoirs can intensify the amount of mercury methylation in an ecosystem [41, 42]. The repeated wetting and drying of water body edges allows the bacteria that methylate mercury to thrive and increase the amount of biologically available mercury. The most reasonable way to control this methylation is to maintain more constant water levels in these reservoirs, particularly in late summer and early fall.

Primary Indicator: rusty blackbird
Secondary Indicator: olive-sided flycatcher, bay-breasted warbler, Canada warbler, Virginia rail, spotted sandpiper

Estuaries

Trace hidden or unknown point sources

Because of its prevalence in various industrial processes and wastewater treatment plants, mercury has historically been released in varying quantities into many different water bodies throughout the United States. Estuaries are often the final destination for this source of mercury, and the high degree of methylation in coastal wetlands allows for much of it to become available to wildlife [35]. Although many of these point sources have known inputs, there are many that are unknown and unexplored. In some cases, the solution can be as easy as discovering and cleaning up the legacy dump site. Without intensive biomonitoring in our nation’s estuaries, we will not be able to determine where these “hotspots” of high mercury levels in wildlife occur.

Primary Indicator: saltmarsh sparrow
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Neotropical Connections

While this report documents mercury concentrations in songbirds on their breeding grounds in the northeastern United States, there is growing concern for birds that migrate to wintering grounds in Central and South America and the Caribbean Islands. Biodiversity Research Institute has gathered evidence that the mercury threat in tropical habitats may be much greater than expected.

Mercury—A Migratory Threat

Mercury is a global pollutant that has a potential to adversely affect hundreds of bird species across the western hemisphere. For migratory species, this means that they can encounter mercury contamination on their breeding grounds, as well as along migratory routes and on their wintering grounds. Moreover, migrating birds might be at greater risk to the toxic effects of mercury. Mercury is stored in muscle; most birds will use their muscle reserves to help fuel their migratory flights especially during stressful times when fat reserves are expended. This muscle burn could potentially give a bird a high dose of mercury during migration.

Migration accounts for nearly 75% of all annual mortality rates in some songbirds; the added burden of toxic mercury exposure may make the process even more challenging. While mercury exposure during the breeding season is well documented, contamination during migration and over the winter is still relatively unknown. Migration is a fascinating natural process, however, its linkages across the world makes understanding the risks of mercury exposure all the more difficult.

Conservation Complexities

Understanding migratory connectivity, the strength of connections between wintering and breeding areas, has become vital to the conservation of migratory birds. When a species has strong connectivity, traditional conservation measures may not be effective. For example, if the New England breeding population of the northern waterthrush (featured at right) was declining and landscape managers wanted to protect it throughout its annual life cycle, one strategy might be to purchase wintering ground habitat and manage it for waterthrushes. If this population only wintered in the Caribbean, then it makes sense to protect it throughout its annual life cycle. Understanding the complexities of migration is crucial to making effective conservation decisions.

BRI’s TERRA Network

BRI has developed the Terrestrial Ecosystems ReseaRch and Assessment (TERRA) Network across the western hemisphere to improve our understanding of mercury threats to migratory birds and bats. Through collaboration with biologists in Canada, the U.S., Mexico, Central and South America, and the Caribbean Islands, we hope to better understand how mercury affects species throughout their life cycle.

BRI has gathered evidence that mercury levels in the northern waterthrush during winter, over migration, and on breeding grounds are similar. Blood mercury concentrations are consistently elevated throughout the year, demonstrating that dietary uptake is a year-round concern, and despite migratory movements this species has less of an ability than some species for ridding its body of mercury burdens during times of low environmental mercury exposure. This “double whammy” of mercury toxicity restricts seasonal depuration or release of mercury.

Neotropical Migrant Songbirds of Conservation Concern*

Olive-sided Flycatcher 40-year decline=80%
Carolian Warbler 40-year decline=70%
Bladpoll Warbler 40-year decline=80–90%
Wood Thrush 40-year decline=50%
Bicknell’s Thrush 40-year decline=No data

*Based on range-wide North American Breeding Bird Survey data

Neotropical Case Study: Northern Waterthrush

Neotropical Case Study: Northern Waterthrush

Figure 15: Depicted here is the northern waterthrush’s breeding (dark green) and wintering (light green) ranges along with migratory routes (arrows). This species is emphasized because it is one of the few neotropical migrants where BRI has year-round information on mercury exposure, but many other declining neotropical migrants are potentially exposed similarly (see box at right).
Although we focus on mercury exposure and effects in this report, there are many other environmental stressors that can act in concert with mercury to create problems for terrestrial ecosystems.

### Acid Rain

Acid deposition is a well-documented environmental stressor with various negative impacts on ecosystems.

- Increased acidity in soil promotes increased methylmercury production, resulting in higher mercury exposure in invertivores.
- Acidic deposition leaches calcium from the soil, resulting in the decreased availability and abundance of calcium-rich invertebrate prey that songbirds eat [32, 44]. Decreased calcium availability for egg production combined with the neurotoxic effects of mercury can potentially lead to nest failure.

### Climate Change

The interaction of environmental mercury and climate change can add additional stress to already threatened species.

- Rising sea levels may lead to loss of coastal wetlands, habitat alterations, and potential changes in mercury cycling in wetlands.
- Rising temperatures could lead to enhanced methylation of mercury for select habitats.
- Increases in precipitation in some parts of the U.S. could lead to increases in atmospheric deposition of mercury.
- Forest fires, expected to increase with global warming, release stored mercury into the environment.
- Changes in food web structure that occur as species adapt to changes in habitat and available food sources may alter mercury exposure.
- More frequent and increased storm intensity could lead to episodes of high mercury exposure as a result of runoff.
- Thawing of permafrost will rapidly release thousands of years of bound mercury (natural and anthropogenic) into the air and water.

There are two goals of this report. First, to characterize the risk of mercury within the terrestrial invertivore community. Second, to offer relevant information for management and policy actions that can be taken to reduce the impact of mercury on the terrestrial ecosystem.

### The Importance of Mercury Monitoring

As we look to the future, how will we know if our management and policy decisions are effective? It is critical to establish mercury monitoring networks, both nationally and internationally, so quantitative assessments can be related with regulatory efforts attempting to lower anthropogenic mercury, particularly in sensitive ecosystems, such as wetlands.

For aquatic systems, we demonstrate encouraging results from the Great Lakes Region, where reduction in mercury emissions has helped decrease the amount of mercury in different fish species over time (see figure at right).

**Figure 16:** Temporal trends in fish fillet mercury concentrations averaged by year across multiple sites in the Great Lakes and inland water bodies in the U.S. Great Lake states and the province of Ontario [45].

Although fish represent direct links to the aquatic ecosystem, their mercury levels do not always align with atmospheric deposition. We postulate that the songbirds and bats highlighted in this report are good candidates for terrestrial indicator species for several reasons:

- **Songbirds and bats are found in all terrestrial habitat types, aiding in comparisons between different habitats and geographic locations.**
- **Blood can be sampled nonlethally in conjunction with many ongoing songbird banding and bat monitoring programs.**
- **Blood mercury concentrations reflect current (~30 day) dietary uptake of methylmercury, meaning that this tissue is responsive to rapid changes in methylmercury in the food web and there are some indications that the deposition of mercury from the air is significantly linked with songbird blood mercury concentrations (BRI unpublished data).**
Using Science to Inform Mercury Policy

The intent of this report is to present an overview of current information about environmental mercury pollution in the terrestrial ecosystems of the northeastern United States and to support and improve ongoing and future investments that address the risk of environmental mercury loads. We have summarized the most recent data related to mercury pollution in the terrestrial ecosystems of the northeastern United States and to support Congress needs to pass legislation authorizing the creation of MercNet, which will allow the federal government to scientifically evaluate the efficacy of policy and management decisions that, in turn, will allow for better decisions in the future and protect past mercury abatement investments. Congress needs to pass legislation authorizing the creation of MercNet, which will allow the federal government to scientifically evaluate the efficacy of policy and management decisions that, in turn, will allow for better decisions in the future and protect past mercury abatement investments.

1. Identify the species, habitats, and regions at risk to mercury exposure

- Establish MercNet [1]
  Legislation for a National Mercury Monitoring Network (MercNet) was introduced into the 112th Congress (to the Senate Public Works and the House Energy and Commerce Committees) and will provide a comprehensive and standard way for measuring mercury in the air, water, soil, as well as in fish and wildlife. Songbirds and bats are nominated as part of the mercury monitoring effort [1, 46].

1. Identify the species, habitats, and regions at risk to mercury exposure
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   2. Address synergistic interactions of mercury with other environmental pollutants
   3. Minimize wildlife exposure by reducing mercury emissions

2. Address synergistic interactions of mercury with other environmental pollutants

- Set air pollution thresholds for ecosystems [47]
  It is time to establish air pollution thresholds to protect and restore U.S. ecosystems. A “critical loads” approach to understanding air pollution impacts requires the assessment of multiple contaminant “loading” to sensitive ecosystems above which significant adverse impacts are detected. This strategy is accepted as superior by the scientific and regulatory communities, and is in use in Europe, Canada, and parts of the United States, but has yet to be used to understand the interaction of mercury with other contaminants. Although critical loads allow for more refined policy decisions, their establishment requires firm commitment and funding in order to enable the most up-to-date scientific determinations.

   Congress should direct the U.S. EPA to implement critical loads for sulfur and nitrogen, along with thresholds for mercury, and the U.S. EPA should use these thresholds to assess progress under the Clean Air Act.

2. Address synergistic interactions of mercury with other environmental pollutants

3. Minimize wildlife mercury exposure by reducing mercury emissions

- Use best available technology [2]
  Technological pollution control for reducing mercury pollution has been enormously successful in the regulation of municipal and medical waste incinerators [49] and the U.S. EPA Mercury and Air Toxics Standards Rule will provide similar reductions for power plants with a goal of 90% less mercury emissions.

   Ensure implementation of this common sense solution to the largest stationary source of airborne mercury—coal-fired power plants.

- Prevent biological mercury hotspots [41]
  While “cap and trade” programs are effective in certain pollution strategies, like those for acid rain components, it is inappropriate for a pollutant like mercury. There is a growing body of evidence that local mercury emission sources, such as from coal-fired power plants, can have significant local effects on downwind ecosystems leading to the development of biological mercury hotspots [41, 50].

   By avoiding mercury “cap and trade” systems, our expectation is to prevent new mercury hotspots from being created across the United States and globally.

- Support UNEP Mercury Treaty [51]
  The United Nations Environment Programme (UNEP) intends to ratify a purposeful use of mercury for small-scale gold mining, chlor-alkali plants, and in manufactured products are planned, while emissions from fossil-fuel burning and other sources are being negotiated.

   The U.S. State Department and the U.S. EPA should continue their international leadership roles in guiding new standards for global mercury pollution as well as in helping set comprehensive and standard monitoring programs. Adding new delegates from other federal agencies, such as the Department of Interior, will help facilitate greater connections with environmental mercury studies and management in the United States.

3. Minimize wildlife mercury exposure by reducing mercury emissions

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Improve mercury monitoring in both aquatic and terrestrial ecosystems across the United States

Set air pollution thresholds for ecosystems [47]
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Avoid mercury “cap and trade” systems

Regulate global mercury emissions

Reduce mercury emissions from coal-fired power plants

Develop science-based policy recommendations for setting air pollution thresholds to protect ecosystems and species

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To learn more about the impacts of mercury on wildlife and people, visit www.briloon.org/hiddenrisk